PRODUCTION OF DIGITAL IMAGE MODELS USING THE ISIS SYSTEM. E. M. Eliason, *U. S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001 (eeliason@usgs.gov).*

Introduction

The Integrated Software for Imaging Spectrometers (ISIS) [1,2] provides to the planetary science community an image analysis and cartographic processing package for the systematic reduction of planetary image data from the Viking, Voyager, Magellan, Clementine, and Galileo missions. A powerful capability of ISIS is the ability to produce Digital Image Models (DIMs) of planetary surfaces starting with raw planetary data. Invesitgators interested in obtaining the freely distributed ISIS system can connect to the World Wide Web site (*http://wwwflag.wr.usgs.gov/ISIS*).

A DIM is comprised of a mosaic of digital images that have undergone radiometric, geometric, and photometric rectification. A DIM provides a uniform cartographic portrayal of a planetary surface mapped in the Sinusoidal Equal-Area projection (although production of other map projections is possible), allowing an investigator to explore the geophysical and compositional properties of a planetary surface on a global or regional scale [3,4,5] . The processing stages in producing a DIM prepare the data for remote sensing investigations by producing spectrally and spatially co-registered images with pixel values in radiometric units. Once a DIM has been produced by the ISIS system, additional ISIS software can be used to enhance, extract, and display spectral and spatial signatures of a planetary surface. Alternatively, the ISIS system can output the DIM in "unlabeled" form for ingestion into other image processing systems.

Raw planetary images are processed in five stages or "levels." All corrections made during these stages have some degree of uncertainty; the processing sequence was designed to process from corrections with highest probability of accuracy to those with the lowest. Intermediate stages of processing are usually preserved, at least temporarily, so that an analyst can return to them later to inspect for processing problems or for future analytical use.

NASA investigators can obtain digital image data for virtually all planetary missions by contacting the Planetary Data System (PDS) Imaging Node [6]. The Imaging Node acts as NASA's curator for the archives of digital images acquired by NASA flight projects. The archives are distributed on CD-ROM multi-volume sets as well as through World Wide Web on-line services. Contact Eric Eliason (eeliason@usgs.gov) for information on how to obtain the planetary image data collections. Visit the Imaging Node's home page on the web (*http://www-pdsimage.jpl.nasa.gov*) for information on how to obtain the planetary image data collections through the Node's on-line services.

Data Processing Stages

ISIS processes data in five stages or levels starting with raw images. The first level of processing, level 0, prepares the data for processing by ISIS. The images are converted to ISIS format and ancillary data such as viewing geometry are added to the labels of the image file. Level 1 processing applies radiometric corrections and removes artifacts from the image. Level 2 performs geometric processing to remove optical distortions and to convert the image geometry to a standard map projection. Level 3 performs photometric processing for normalizing the sun-viewing geometry of an image scene. Level 4 performs mosaicking of individual images to create global or regional views for the planet surface.

Level 0 - Data Ingestion

The Level 0 processing step prepares the raw image data and associated meta-data for processing by the ISIS system. Level 0 processing usually consists of two program steps. The first step reads the format of the raw image and converts it to an ISIS file. Additionally this step will extract the meta-data from the input image labels for inclusion into the ISIS label. The meta-data may contain information such as the instrument operating modes, temperature of the camera focal plane, UTC time of observation, and other information necessary to rectify an image. The second step extracts navigation and pointing data ("SPICE" kernel data) for inclusion into the ISIS file.

Level 1 - Radiometric Correction

The next level of processing, Level 1, performs radiometric correction and data clean-up on an image. Level 1 consists of a series of programs to correct or remove image artifacts such as 1) camera shading inherent in imaging systems, 2) artifacts caused by minute dust specks located in the optical path, 3) microphonic noise introduced by operation of other instruments on the spacecraft during image observations, and 4) data drop-outs and spikes due to missing or bad data from malfunctioning detectors or missing telemetry data. Level 1 processing results in an "ideal" image that would have been recorded by a camera system with perfect radiometric properties (although in practice residual artifacts and camera shading remain). The density number (DN) values of a radiometrically corrected image are proportional to the brightness of the scene.

Level 2 - Geometric Processing

Producing DIMs requires geometric processing to be performed on the individual images that make up a DIM. The individual images are geometrically transformed from spacecraft camera orientation to a common map coordinate system of a specific resolution. Before geometric transformation, images must first be geometrically "matched" to each other to establish relative geometric control among the images and then the image set must be "tied" to a ground control net to establish absolute ground truth. The process of matching images and tying the image set to ground truth minimizes the spatial misregistartion along image boundaries and produces high-quality DIMs.

Level 2 performs geometric processing which includes correcting camera distortions as well as transformation from image coordinates to map coordinates [7]. All geometric transformations are made simultaneously so that an image is resampled only once and resolution loss is minimal. In the creation of a DIM the analyst should select an output resolution slightly greater than the input image resolution so that the image is to some extent oversampled (i.e., the output image has more lines and samples than the original image). The image transformation is based on the original viewing geometry of the observation (including the optical distortion model of the camera), relative position of the target, and the mathematical definition of the map projection.

Sub-pixel Color Registration

Pixel-to-pixel misregistration between images acquired through different spectral filters can be a major source of error in the spectral analysis and mapping of planetary soils. A series of ISIS programs have been developed that resample highly correlated images for co-registration to an accuracy of better than 0.2 pixels. These procedures are automated for color filter sets that are initially matched to within a few pixels. If sub-pixel coregistration is not performed on color sets then subsequent image enhancement processes, such as color ratio analysis, can cause “color fringe” artifacts in areas of high spatial frequency content.

Level 3 - Photometric Normalization

Photometric normalization is applied to images that make up a DIM in order to balance the brightness levels among the images that were acquired under different lighting conditions. To illustrate, consider two images of the same area on the planet where one image was acquired with the sun directly overhead and the second with the sun lower to the horizon. The image with the higher sun angle would be significantly brighter than the image with the low sun angle. Photometric normalization of the two images would cause them to be adjusted to the same brightness level.

Radiometrically calibrated spacecraft images measure the brightness of a scene under specific angles of illumination, emission, and phase. For an object without an optically significant atmosphere, this brightness is controlled by two basic classes of information: 1) the intrinsic properties of the surface materials, including composition, grain size, roughness, and prorosity; and 2) variations in brightness due to the local topography of the surface [8]. Photometric normalization is effective only to the extent that all geometric parameters can be modeled. In general the local topography is not included in the model (i.e. the planetary surface is thought of as a smooth sphere). However, illumination geometry at each pixel certainly depends on local topography; unless the topographic slope within a pixel is accurately known and compensated, the photometric correction cannot be perfect.

Level 4 - Seam Removal and Image Mosaicking

In spite of best efforts at radiometric calibration and photometric normalization, small residual discrepancies in image brightnesses are likely to remain. These brightness differences appear as “seams” in a mosaic. A method has been developed that performs adjustments in the image brightness levels to better match the brightness along the boundaries of neighboring (overlapping) frames.

The seam removal process is two-fold. First, a program is run on all neighboring pairs of images that compares the brightness differences in overlapping areas. The brightness information is stored in the labels of each image. A second program extracts the brightness information for all images that make up the DIM and computes a correction factor (multiplicative and additive coefficients) for each image. After applying the correction factors to each image, the resulting brightness differences will be minimized.

Compilation of an accurate digital mosaic of the individual images is the final stage in the construction of a DIM. The final DIM is created by first creating a blank (or null) image that represents the regional or global image map of the analyst’s research area. The individual images are then mosaicked into the initially blank DIM. The order in which individual images are placed into the mosaic is an important consideration. Because images are mosaicked one on top of the other, images that get laid down first are overwritten in the area of overlap with subsequent images that are added to the mosaic. It is preferable to first lay down images that have the lowest data quality followed by images with highest quality. In this way the areas of image overlap contain the highest quality images.

Summary

The ISIS system has the ability to perform radiometric, geometric, and photometric processing on the planetary image data collections from NASA flight projects. DIMs, comprised of a mosaic of rectified images, provide a uniform cartographic portrayal of a planetary surface mapped in the Sinusoidal Equal-Area projection, allowing an investigator to explore the geophysical and spectral properties of a planetary surface on a global or regional scale.

References: [1]Torson, J. and Becker, K.J., 1997, ISIS - A Software Architecture For Processing Planetary Images, *This Issue*. [2]Gaddis L. R., et al., 1997, An Overview of the Integrated Software For Imaging Spectrometers (ISIS), *This Issue*. [3] Batson, R.M., 1987, Digital Cartography of the Planets: New Methods, Its Status, and Its Future, *Photogrammetric Engineering and Remote Sensing*, Vol. 53, No. 9. [4]Batson, R.M. and Eliason, E.M., 1995, Digital Maps of Mars, *Photogrammetric Engineering and Remote Sensing*, Vol. 61, No. 12. [5]McEwen, A.S., et al., 1991, Digital Cartography of Io, *Lunar Planet. Sci*. XXII. [6]Eliason, E. M., et al., 1996, The Imaging Node for the Planetary Data System, *Planetary and Space Science*, Vol. 44, No. 1. [7]Edwards, E., 1987, Geometric Processing of Digital Images of the Planets, *Photogrammetric Engineering and Remote Sensing*, Vol. 53, No. 9. [8]McEwen, A.S., 1991b, Photometric Functions for Photoclinometry and Other Applications, *ICARUS*, Vol. 92.